On-orbit Results of Pointing, Acquisition, and Tracking for the TBIRD CubeSat Mission

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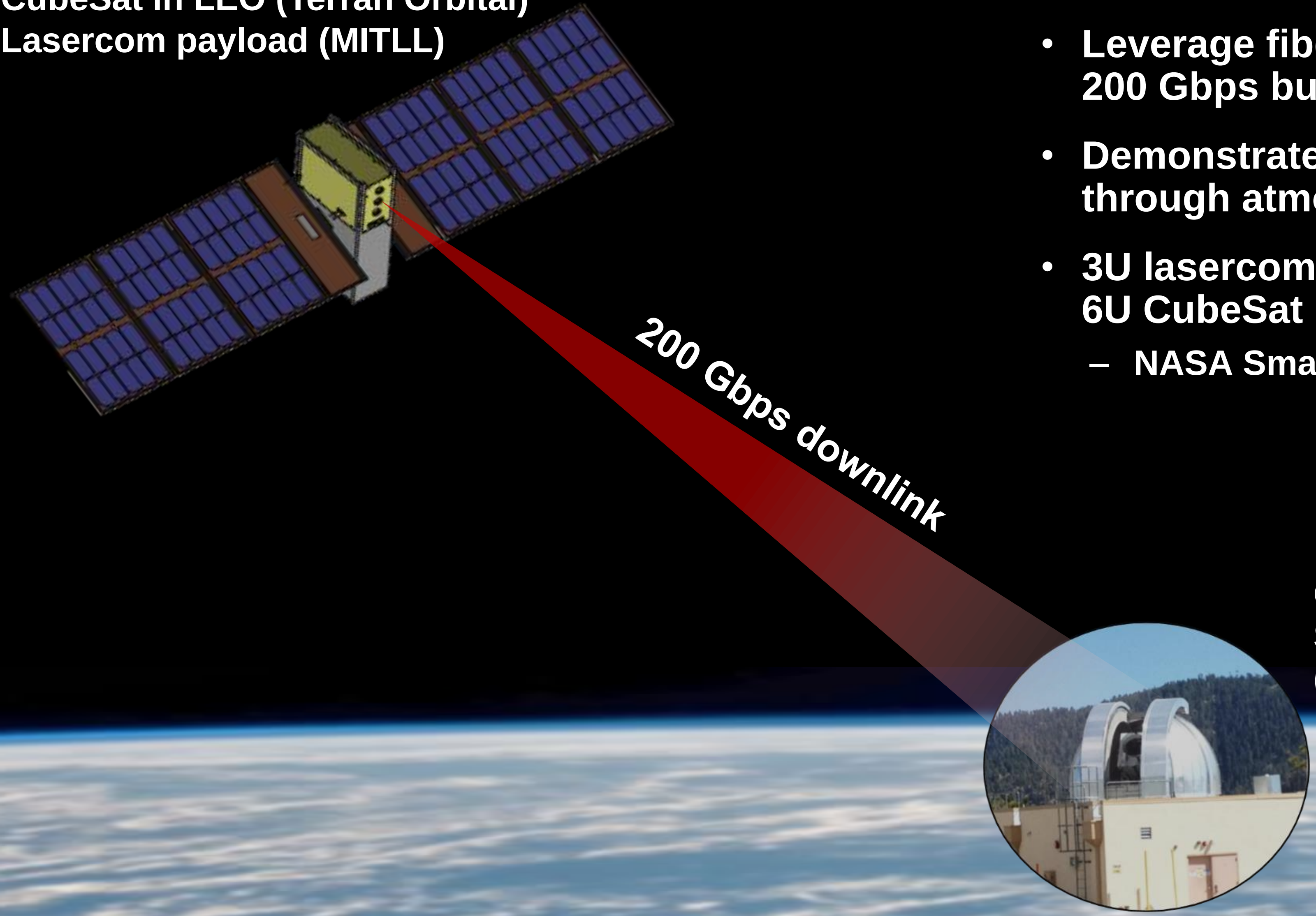
Terabyte Infrared Delivery (TBIRD)

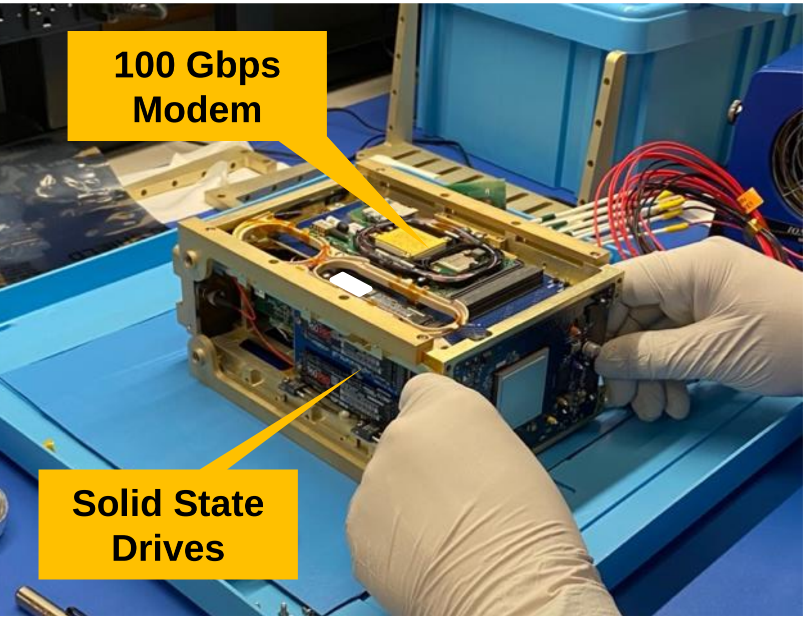
6U CubeSat in LEO (Terran Orbital)
3U Lasercom payload (MITLL)

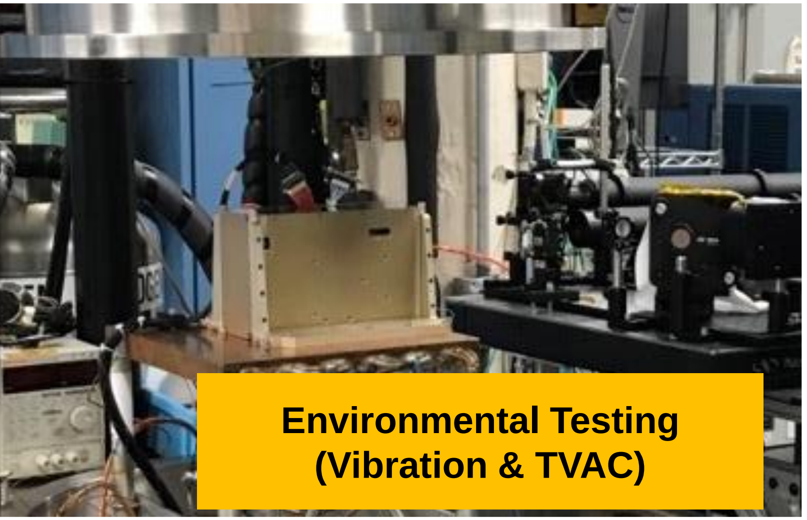


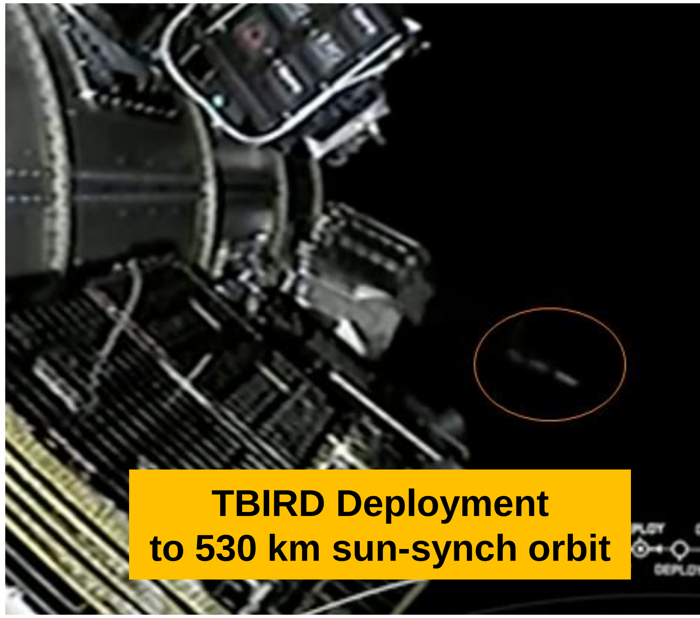
- Leverage fiber telecom equipment for 200 Gbps burst delivery (TBs per pass)
- Demonstrate robust data transfer through atmospheric channel
- 3U lasercom terminal payload hosted on 6U CubeSat
  - NASA Small Sat Pathfinder Tech Demo

Ground terminal at OCTL in Southern California (MITLL & JPL)

TBIRD Demonstration

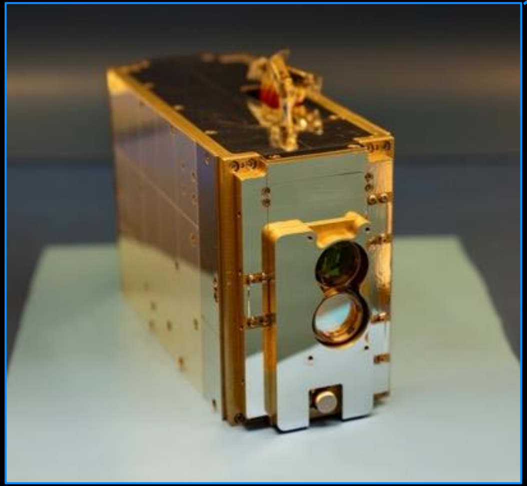


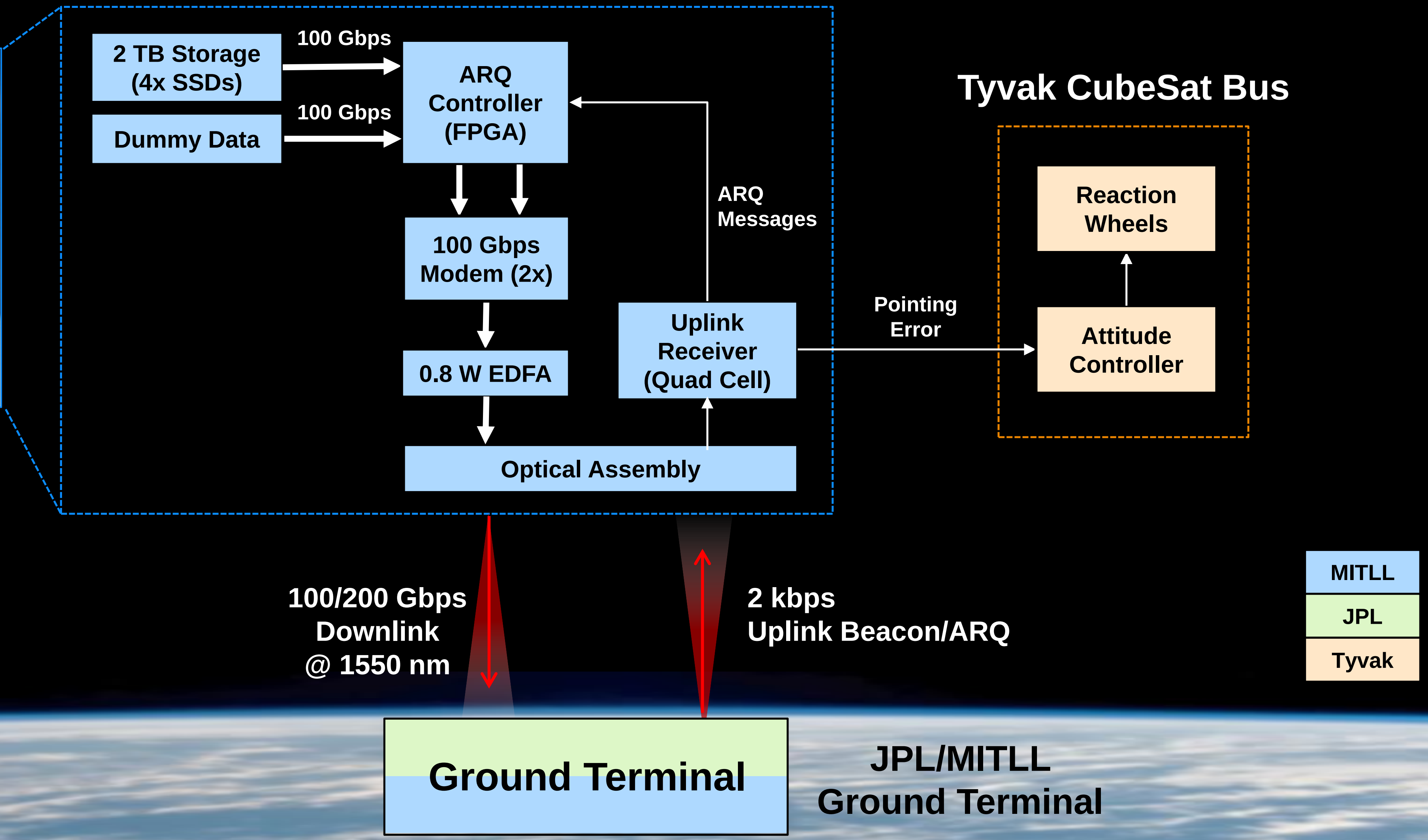




Communication and Body-Pointing Architecture

MITLL Lasercom Payload

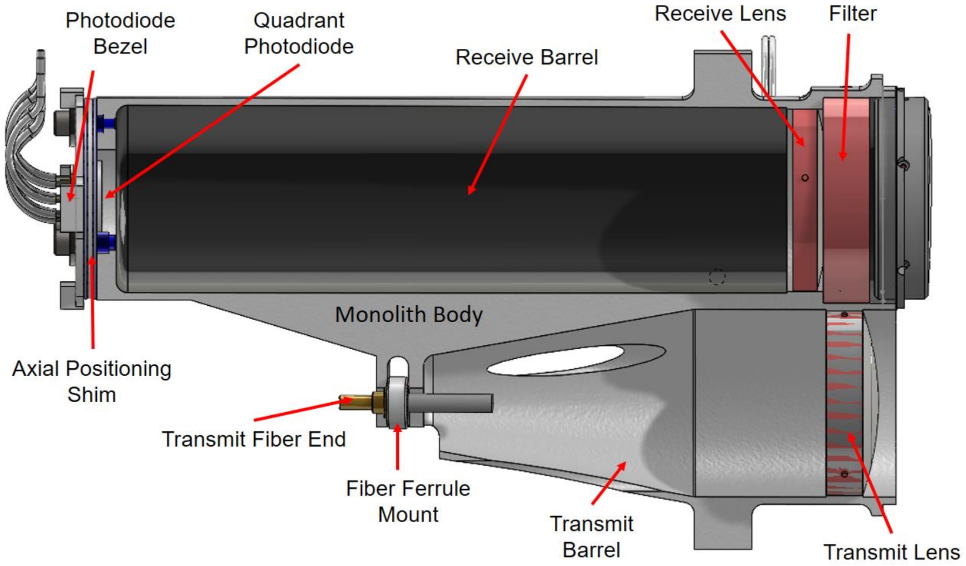


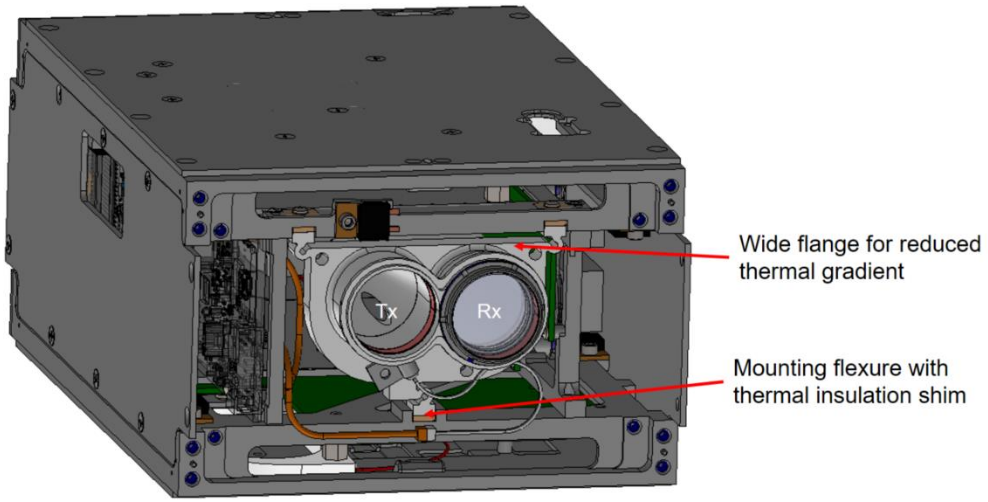


ARQ: Automatic Repeat reQuest
SSD: Solid State Drive
EDFA: Erbium Doped Fiber Amplifier

Optical Assembly

- **Bistatic design to reduce complexity**
- **Payload draws 105 W in 200 Gbps mode, resulting in self-heating**
- **Custom optical assembly was designed to maintain Tx/Rx alignment stability**
  - **Thermal isolation from electronics**
  - **Large thermal mass**
- **Quad sensor enables spatial tracking of uplink**
  - **Offset tracking to compensate for point ahead and Tx/Rx misalignment**





State-of-the-Art in Nanosatellite Pointing

- **Nanosatellite pointing has improved 1000x in the last decade: ~2° to ~0.002°**
  - **COTS options available from individual components to full ADCS to entire bus**
  - **Still relatively few precision pointing CubeSat missions**
- **ASTERIA mission is best pointing to date (inertially pointed)**
- **OCSD demonstrated precision ground tracking for lasercom from a CubeSat (beaconless)**
- **TBIRD is the first lasercom mission to demonstrate architecture of body-pointing with closed-loop payload feedback**

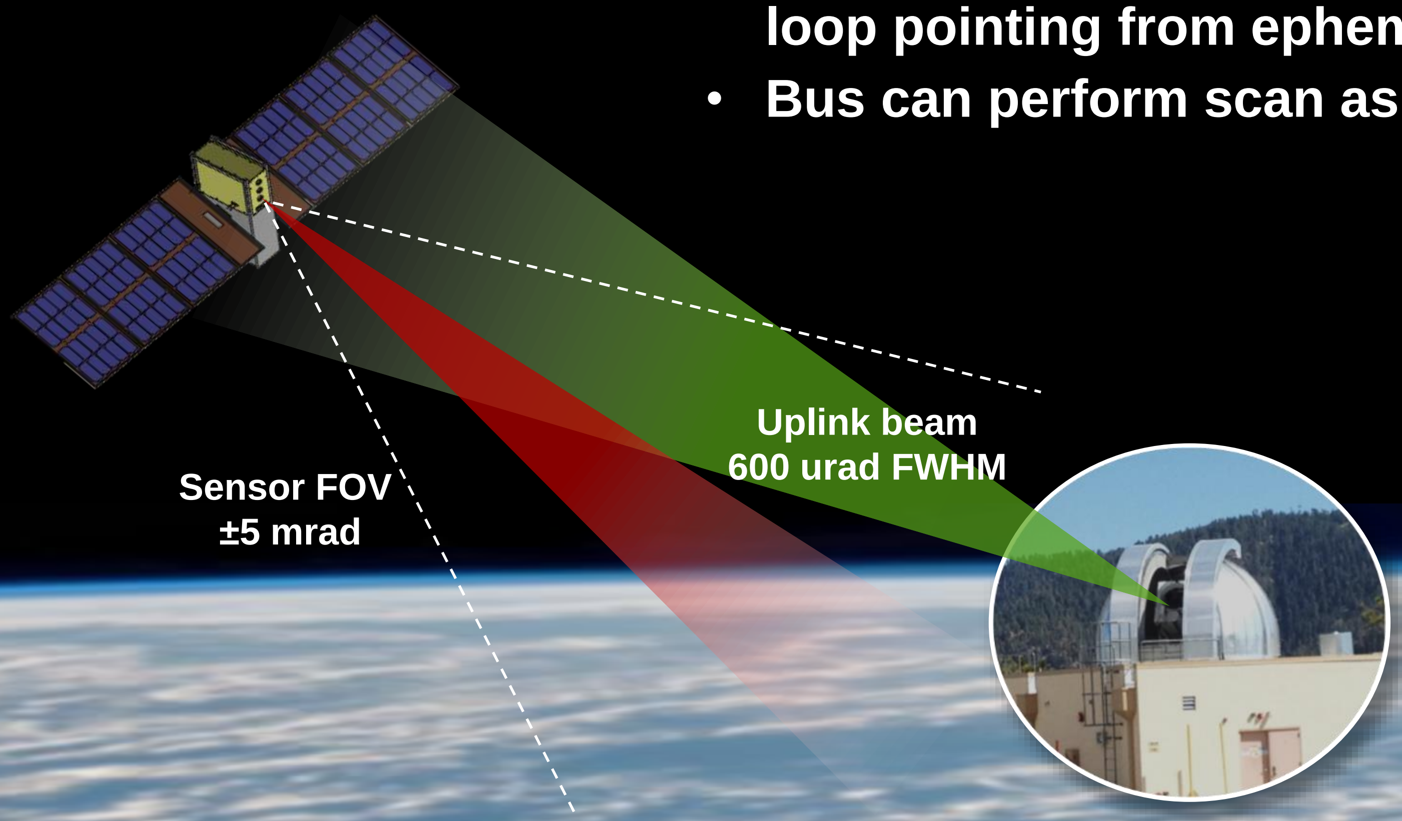
Year	Mission	Organization	ADCS Vendor	Pointing Accuracy
2013	BRITE	UTIAS-SFL	Sinclair Interplanetary	262 urad (RMS, 2-axis)
2016	MinXSS	UC Boulder	Blue Canyon Technologies	73−204 urad (3σ, 1-axis, axis dependent)
2017	ASTERIA	JPL	Blue Canyon Technologies	**8.7−22 urad (RMS, 1-axis, axis dependent)**
2018	AeroCube-7/OCSD	Aerospace Corporation	In-house	419 urad (3σ, 1-axis)
2022	TBIRD/PTD-3	MITLL/Terran Orbital	Terran Orbital	**20−35 urad (RMS, 1-axis, axis dependent)**

ADCS: Attitude Determination and Control System

Pass ConOps

Acquisition

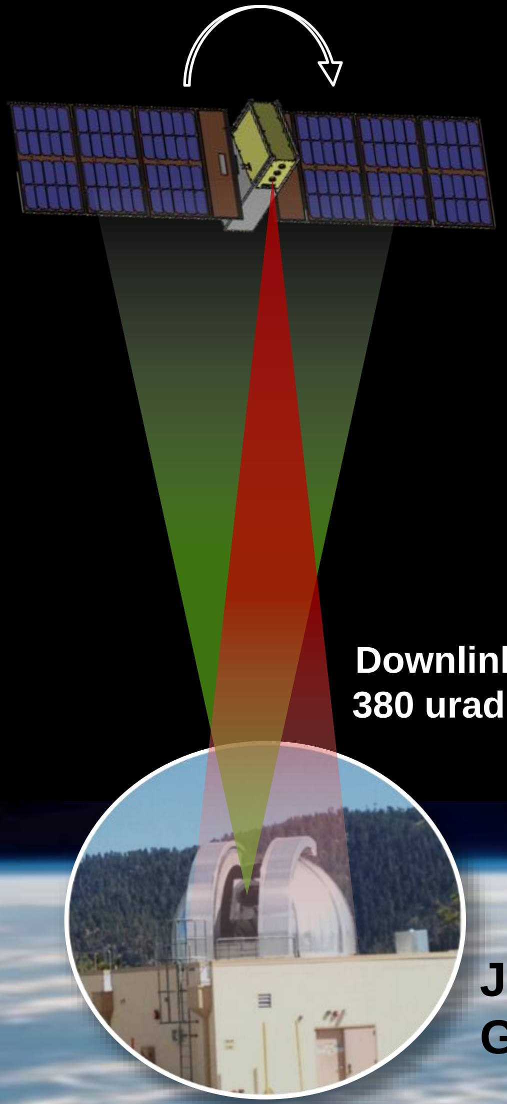
- Bus open-loop points within field of view of TBIRD quad sensor
- Ground station illuminates TBIRD by open-loop pointing from ephemeris (TLE)
- Bus can perform scan as a contingency



JPL/OCTL
Ground terminal

FOV: Field of view
FWHM: Full width half max
OCTL: Optical Communications Telescope Laboratory
TLE: Two Line Element

Pass ConOps



Downlink beam
380 urad FWHM

JPL/OCTL
Ground terminal

Tracking

- Body-pointing only, no additional actuators
- TBIRD sends 2-axis pointing feedback to bus
- Bus tracks payload feedback to support high-rate downlink

FWHM: Full width half max
OCTL: Optical Communications Telescope Laboratory

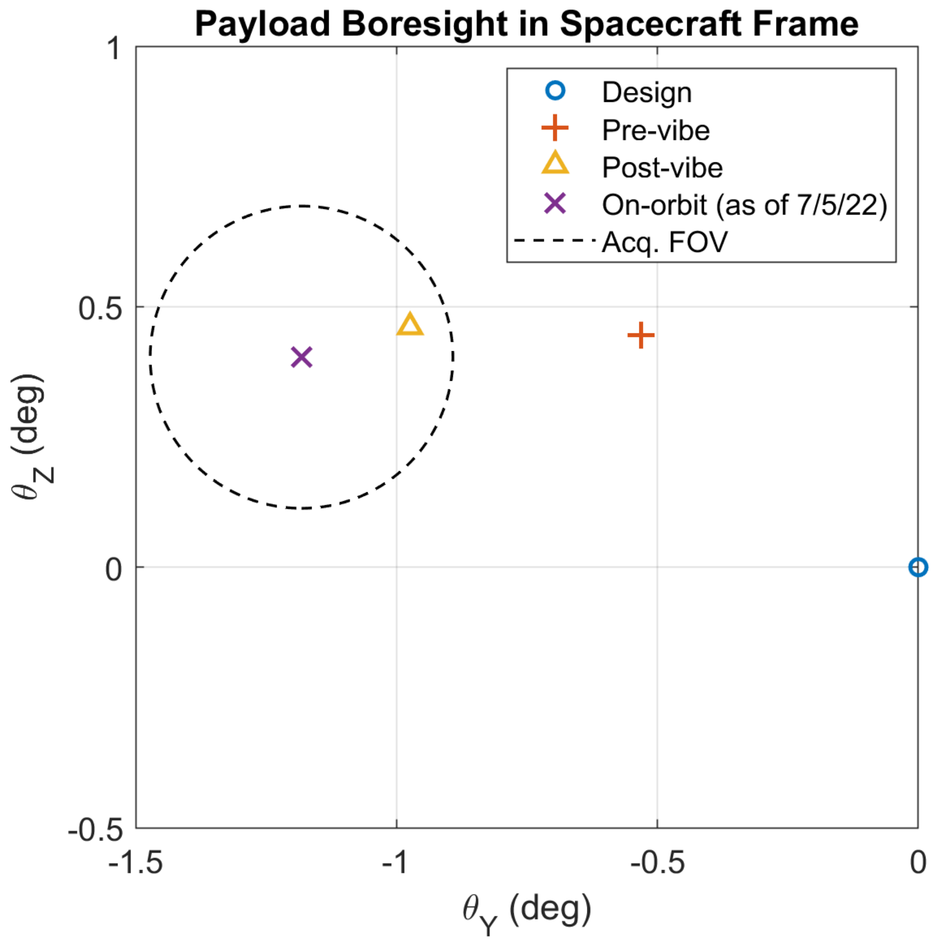
Initial Uplink Detection

- **Required steps for uplink detection**
  1. **Ground station illuminates spacecraft**
  2. **Spacecraft points at ground station within sensor field of view**

- **Primary sources of pointing error**
  – **Ground station: ephemeris error**
  – **Spacecraft: payload boresight uncertainty**

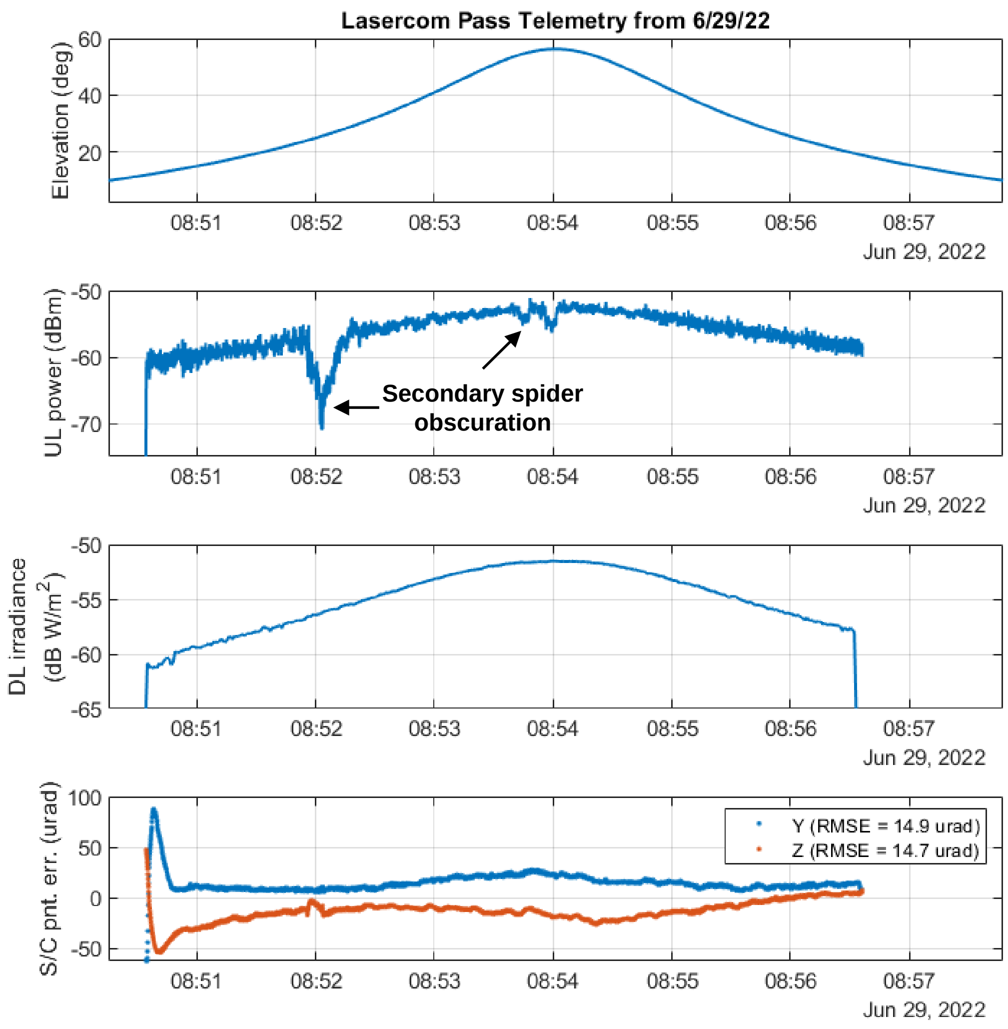
- **Payload boresight measured on ground, but some shift expected due to launch**

- **Payload boresight shift was within sensor FOV enabling acquisition without scan**



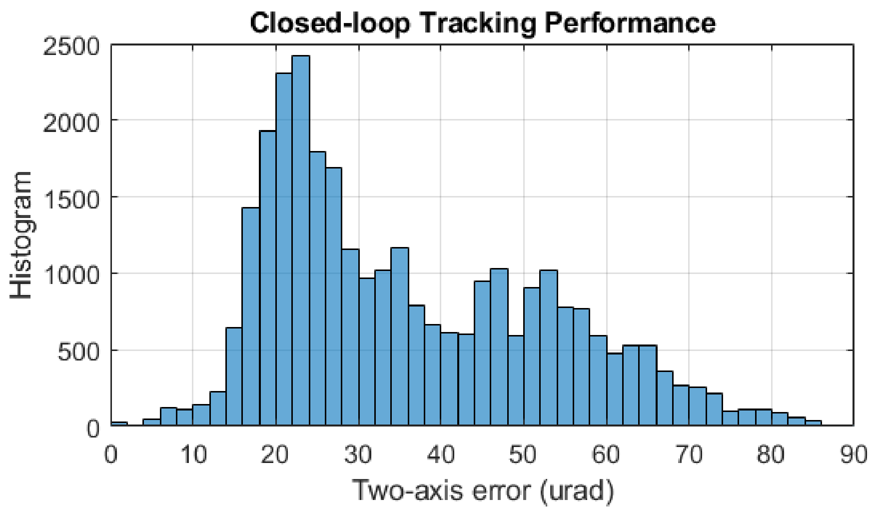
Sample Telemetry from 6/29/22, 500 GB Downlinked

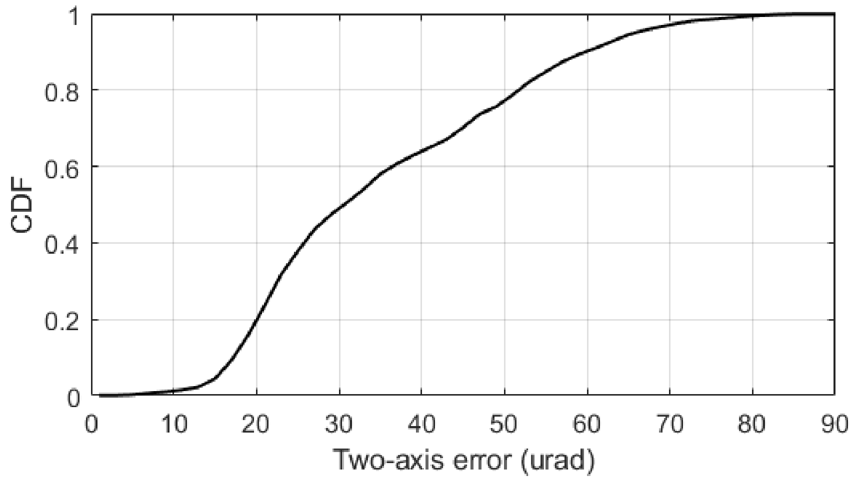
- **Uplink detection occurs at 12° elevation (~1600 km), pass ends at 20° descending**
- **Bus takes about 20 seconds to pull-in**
- **Observed uplink power dips are due to telescope spider interference**
- **In this pass, pointing error is about 15 urad RMS per axis**
- **Pointing error dominated by a low frequency (<0.02 Hz) drift**



Closed-loop Tracking Performance

- **Data from 18 passes, ~50 minutes of data at 10 Hz**
  - **Excludes off-nominal passes**
  - **Excludes pull-in time**
- **Two-axis pointing statistics:**
  - **50% of time error <30 urad**
  - **90% of time error <60 urad**
- **Per-axis pointing statistics:**
  - **Y RMS error 35 urad**
  - **Z RMS error 20 urad**
- **Low-frequency pointing error could be reduced with controller modification**
- **Pointing loss typically <0.1 dB for 380 urad FWHM beam**

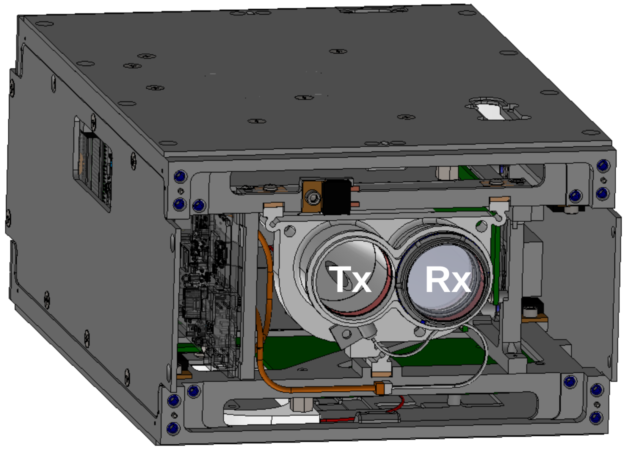


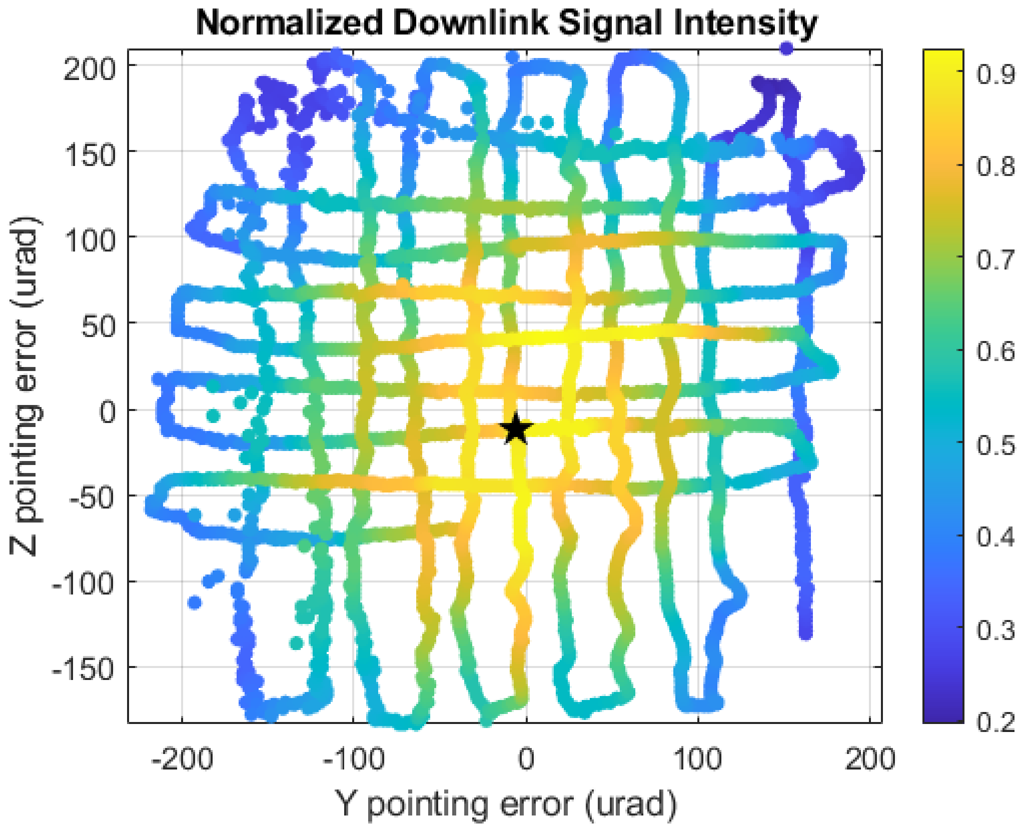


FWHM: Full Width Half Max

Downlink Beam Characterization

- **Two passes were used to perform downlink beam characterization**
  - **Offsets injected into payload feedback to steer the bus in a grid**
  - **Power measured at ground station**
- **Measured beamwidth of 380 urad FWHM**
- **Confirmed Tx/Rx alignment has been maintained to within 20 urad**





FWHM: Full Width Half Max

Summary

- **TBIRD/PTD-3 launched in May 2022 and has operated successfully for six months**

- **Key achievements:**
  - **100/200 Gbps downlinks from LEO**
  - **Downlinked >1 TB error-free in a pass**
  - **Demonstrated 20−35 urad (RMS, per axis) closed-loop body pointing on a Cubesat**

- **Mission will continue in 2023**